2018-03-05

Towards a SAR System for Personalized Cardiac Rehabilitation: A Patient with PCI

Casas, J

http://hdl.handle.net/10026.1/16701

Towards a SAR System for Personalized Cardiac Rehabilitation: A Patient with PCI

Jonathan Casas
Colombian School of Engineering
Bogota, Colombia
jonathan.casas@escuelaing.edu.co

Bahar Irfan
CRNS, Plymouth University, UK
bahar.irfan@plymouth.ac.uk

Emmanuel Senft
CRNS, Plymouth University, UK
emmanuel.senft@plymouth.ac.uk

Luisa F. Gutiérrez
Fundación Cardioinfantil-IC
Bogota, Colombia
luisis81@yahoo.com

Monica Rincon-Roncancio
Fundación Cardioinfantil-IC
Bogota, Colombia
mrinron@hotmail.com

Marcela Munera
Colombian School of Engineering
Bogota, Colombia
marcela.munera@escuelaing.edu.co

Tony Belpaeme
IDLab, Ghent University, Belgium
CRNS, Plymouth University, UK
tony.belpaeme@plymouth.ac.uk

Carlos A. Cifuentes
Colombian School of Engineering
Bogota, Colombia
carlos.cifuentes@escuelaing.edu.co

ABSTRACT

Physical activity has been shown to have multiple benefits, such as reducing mortality rate caused by cardiovascular diseases and providing an optimal health status, making it one of the most important components of cardiac rehabilitation (CR) programs. However, the adherence to the program is low, and finding strategies to motivate people to perform physical training is a priority. This work proposes the introduction of a socially assistive robotics system in order to provide monitoring and motivation to patients within a CR program. A study was carried out with one patient accompanied by the robot during a conventional phase II, namely 16 sessions of the cardiac rehabilitation program. The results show the reliability of the system to provide information to assess the patient's performance during the activity. Additionally, the patient was able to improve his posture patterns along the sessions due to the continuous monitoring provided by the robot.

ACM Reference Format:
Jonathan Casas, Bahar Irfan, Emmanuel Senft, Luisa F. Gutiérrez, Monica Rincon-Roncancio, Marcela Munera, Tony Belpaeme, and Carlos A. Cifuentes. 2017. Towards a SAR System for Personalized Cardiac Rehabilitation: A Patient with PCI. In *Proceedings of (HRI'18)*. ACM, New York, NY, USA, 7 pages. https://doi.org/

1 INTRODUCTION

Regular physical activity is fundamental in human health: it improves the level of fitness and the quality of life, whilst decreasing the risk of falling and preventing osteoporosis [4]. Physical activity also reduces deaths caused by cardiovascular diseases (CVD's) and can improve cardiovascular risk profile, hence, providing an optimal health status [3]. For this reason, most of the cardiac rehabilitation (CR) programs, which refers to the commonly used therapy method to prevent CVD's or to treat a patient after a CVD event, include physical activity as a core component. CR covers a range of areas, such as nutrition and weight management, assessment and management of depression, physical exercise and comorbidities, health education and medical therapy [12]. Traditionally these therapies are divided into three phases, namely inpatient (phase I), outpatient (phase II) and long-term intervention (phase III) [16]. According to the World Health Organization[1], around 17.5 million people die each year from CVD's. This number represents approximately 31% of all deaths worldwide. Similarly, in 2015 two CVD's were leading the death cause list in the world: ischaemic heart disease (8.76 million deaths) and stroke (6.24 million deaths) and around 80% of all deaths from CVD's are a consequence of heart attacks and strokes. These facts show that CR plays a key role in one of the most critical health problems worldwide.

However, despite the importance of following the whole CR therapy, the adherence to the program does not reach a desirable level: the desertion rate is high. A study shows that people at high cardiovascular risk have demonstrated a high prevalence of unhealthy lifestyles, increasing risk factors and inadequate use of drug therapies to achieve blood pressure and lipid goals [16]. Most recently, a survey of coronary patients shows that after a median time of 1.35 years after their acute event, 48.6% of patients who were smoking at the time of their event persisted in smoking and little or no physical activity was reported in nearly two thirds of interviewees [16]. Due to this fact, taking action to promote and encourage people to enhance their physical condition and adopt healthy habits by attending to CR programs is a priority.

Socially Assistive Robotics (SAR) have been introduced in 2005 in [5]. Authors make the distinction between physically assistive robotics where a robot provides physical/mechanical support for a patient to help him recover, and socially assistive robotics, where a

HRI'18, March 5-8, 2018, Chicago, IL USA

[1] http://www.who.int/cardiovascular_diseases/en/

robot is emotionally supportive by providing feedback, instructions and encouragement to increase the motivation of the patient. SAR has been applied to a large variety of domains with applications ranging from socially assistive tools at home [9, 11], receptionist in public space [6, 7, 18], teachers in an educational setting [8] to coaches for rehabilitation [15]. In [17], authors show that physical exercise instructed by robot was significantly more effective than requested by a human instructor. Additionally, SAR has been used with patients suffering dementia: the robot illustrates and guides the patients during the exercises and physical activities, obtaining as result that neuropsychiatric symptoms tend to improve over those of patients following classic therapy methods [14]. Moreover, a review carried out by [2] shows that most of the elderly like robots and present a better response in the activities accompanied by them. Finally it has been also demonstrated that an embodied agent can have more impacts than a human-computer interface (HCI) or a virtual agent [1, 10].

As stated before, the presence of an embodied agent could provide more benefits in exercising and rehabilitation scenarios. hence, this work aims to evaluate and to provide preliminary results of a Human-Robot system for exercising implemented within a cardiac rehabilitation program. In this paper, we present the results of a conventional phase II (8 weeks) of a therapy for a patient with percutaneous coronary intervention (PCI) using a sensor suite that measures mainly six parameters (heart rate, cadence, step length, speed, inclination and the Borg scale, namely the level of exertion during physical activity) and are recorded in real-time. This sensor interface is described in more detail in [13].

2 METHODOLOGY

The goal of this work is twofold: identifying the key motivational aspects of SAR assessed through a questionnaire (Section 2.1 and presenting results of a case study using a SAR platforms (Section 2.2) with a patient recovering from PCI (Section 2.3).

2.1 Questionnaire

In order to understand the opportunities of SAR in the context of CR, a questionnaire was distributed to 238 patients with different cardiac diseases, which allowed collecting anthropometric data such as gender (83 females and 155 males), age (M=62.3 years, SD=14.3), weight (M=68.46 kg, SD=12.12) and height (M=1.64 m, SD=0.09), along with the opinions and perceptions of the patients about the CR sessions and the integration of SAR. Here we analyse two of the questions, which are of importance to this paper.

The former question focused on the approach of the patients on the sessions: *"What aspects do you like about the cardiac rehabilitation session on the treadmill?"* with the possibility to choose one of the following answers: *"technology"*, *"sessions"*, *"institution"*, *"results"*, and *"physical ability improvements"*. The choices were based on the general opinions obtained from the patients in a prediagnosis.

The opinion of the patients on the integration of a social robot in the CR process was assessed by the other single-choice question *"How would you feel about a social robot accompanying you throughout the rehabilitation process?"*, followed by: *"curiosity"*, *"interest"*, *"doubts"*, *"discomfort"* and *"prefer without robot"*. Patients who refused or selected a negative option were asked to express their reasons.

2.2 Human-Robot Interface

Fig 1 presents the setup: a social robot (NAO, SoftBank Robotics Europe) provides feedback and instructions to the patient based on the data acquired from the sensors and the tablet. The tablet is used to receive inputs from the patient and combines measurements from a set of sensors to decide the behaviour of the robot based on certain rules, such as the timing of requests, the threshold of heart rate, and the exertion level, determined by the therapists.

Each sensor provides the values of the variables used by the therapists to monitor the progress of the therapy:

- *cardiopulmonary parameters*: peak heart rate, heart rate variability and evolution of heart rate
- *gait spatiotemportal parameters*: cadence, step length and speed
- *parameters of physical activity intensity*: Borg Scale (BS), which refers to the level of exertion

The BS is requested by the robot every three minutes, which is obtained from the patient through the GUI on the tablet (Fig 2). The GUI also provides bio-feedback and shows the performance of the patient during the session. Finally, the inclination of the treadmill is measured with an inertial measurement unit. Detailed information about this interface can be found in a previous developed work [13].

The robot is placed on the side of the treadmill, below the eye level of the patient. Once the therapy begins, the robot stands in order to draw the attention of the patient and starts the interaction. The sensor suite provides the robot with the data in real-time enabling the robot to respond to the patient's performance and status. The behaviour of the robot can be classified into three states:

Motivation: the robot provides motivation to the patient by saying something amusing or encouraging to increase or maintain motivation, every 5 minutes.

Warning: when any of the risk factors associated to the therapy is perceived, the robot enters the warning state. The most important risk factor to control is the unexpected increase in the heart rate. Once an increment of this parameter is perceived, the robot asks the patient whether everything is fine or medical staff should be called. If the patient reports that everything is going well, the therapy continues normally. However, if the response is negative or a response is lacking, the robot changes to the **Emergency** state. Another risk factor that is controlled in this state is dizziness and the possibility of falling. To avoid this issue, the robot monitors the patient's posture with a camera and asks the patient to correct his posture.

Emergency: this state is triggered when the existence of a risk factor is confirmed and can be set in three different scenarios: (1) when the warning state changes to the emergency state; (2) when the robot detects an excessive increase in heart rate, and (3) when the alarm is triggered by the patient through the GUI (pain, dizziness or fatigue). The robot alerts the medical staff while indicating the type of the emergency.

The behaviour of the robot is fully autonomous and the intervention is based on verbal expressions which are animated by the contextual text to speech module in Naoqi[2] for obtaining a more natural interaction. For example, for the motivation state, the robot uses expressions[3] such as *"Keep it up", "You are doing well", "I'm sure you can do it"*, to encourage the patient. Additionally, in the warning state, utterances such as *"You seem like you are starting to get tired, is everything alright?"* is used when a high exertion is noticed, whereas in the emergency state, the robot calls the doctor directly with a phrase *"Your heart rate is too high, I am calling for help"*, when the heart rate exceeds the desired level.

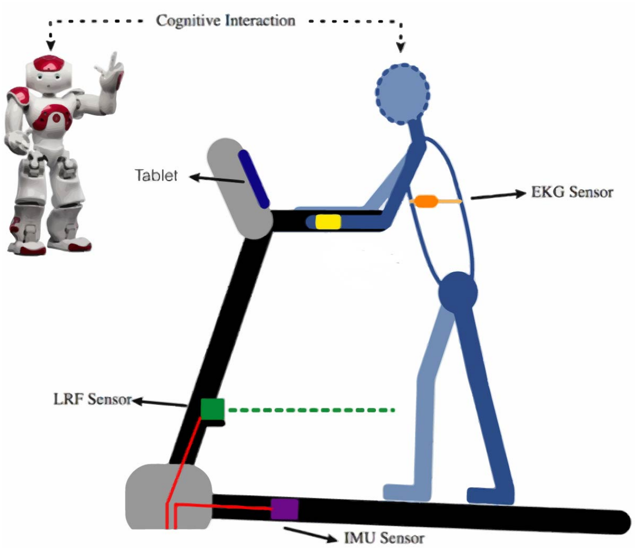

Figure 1: The design of the setup for cardiac rehabilitation with a social robot

2.3 Case Study

A conventional rehabilitation session of the phase II is conformed by a group of 15 to 20 patients and is divided into three stages, namely the warm-up (patients start performing stretching and warming-up exercises), physical activity (patients exercise on the treadmill between 15 and 20 minutes) and finally cool-down (where patients step out from the treadmill and low intensity exercises are carried out). During the warm-up and cool-down stages the staff measure the initial and final heart rate as well as the initial and final blood pressure. Furthermore, while the physical activity on the treadmill is being performed, the medical staff ask regularly the Borg scale, to asses the exertion that the patient is perceiving. A normal experiment takes place within the normal session, where the patient that is being tested follows the same procedure as the normal patients do. However, there is always one observer that is aware of the safety and keeps the system in operation. Although the experimenter is in the room, he does not interfere in the therapy.

An experimental study was designed with the main objective to observe the functionality and usability of the Human-Robot interface and the interaction between the patient and a social robot. To

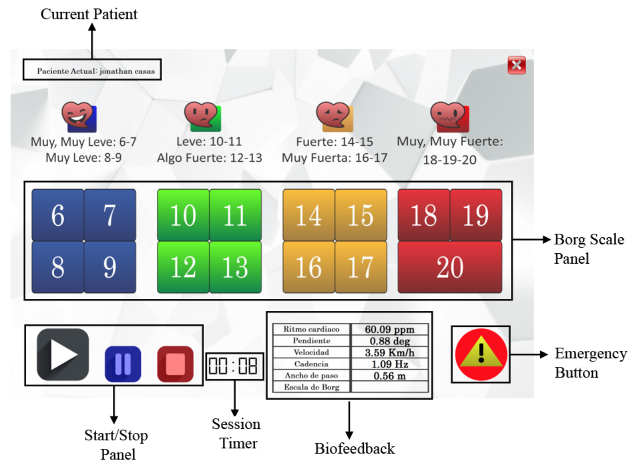

Figure 2: Graphical User Interface

achieve this goal, a case study has been proposed with a single patient who has started and completed the phase II of the CR program and has fulfilled all the requirements to pass to the phase III. The patient that has taken part within the study attended and successfully completed 16 sessions accompanied by the social robot, which has monitored and followed his performance during the entire process. In order to evaluate and analyse the interaction between the patient and the robot, three classes of data have been measured and extracted from the interface. (1) Physiological data: Heart rate and speed of the patient are considered as the main analysis parameters. (2) Data related to the direct interaction that the patient experiences with the robot, like the response time (how much time it takes for the patient to respond to the robot's request) and the interventions that the robot performed to correct the posture of the patient during the exercise. (3) The Borg Scale as a metric for the intensity perception of the patient during the physical activity.

3 RESULTS

The results of the preliminary questionnaire and the case study are presented below.

3.1 Questionnaire

Regarding the positive aspects of CR program (Fig 3), the patients mostly prefer (37%) the "physical ability improvement", whereas, 28% of them selected "others", while expressing that they like all of the options. Moreover, 13% of patients prefer "results", 10% of patients selected the "institution" and only 8% and 4% chose "technology" and "sessions" respectively.

According to the second question (Fig 4), the perception of the integration of SAR in the CR program, 39% of the patients feel curiosity and 27% patients are interested. However, 23% of patients prefer the sessions to be without a robot, 8% patients have doubts and 3% stated that they would feel discomfort.

[2]http://doc.aldebaran.com/2-1/naoqi/audio/alanimatedspeech.html
[3]The phrases presented here are translated from Spanish, which is the language used by the robot during the therapy.

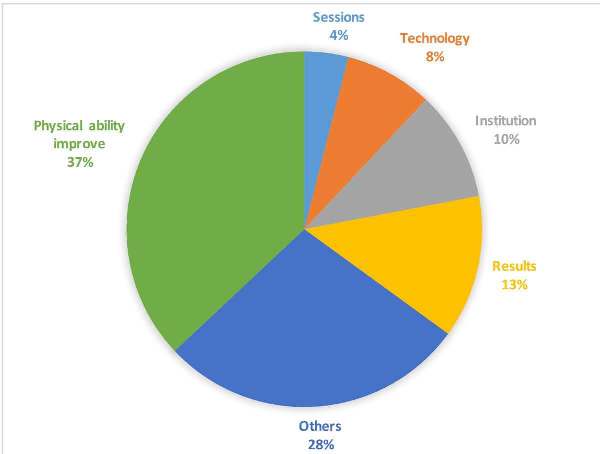

Figure 3: Positive aspects of CR program

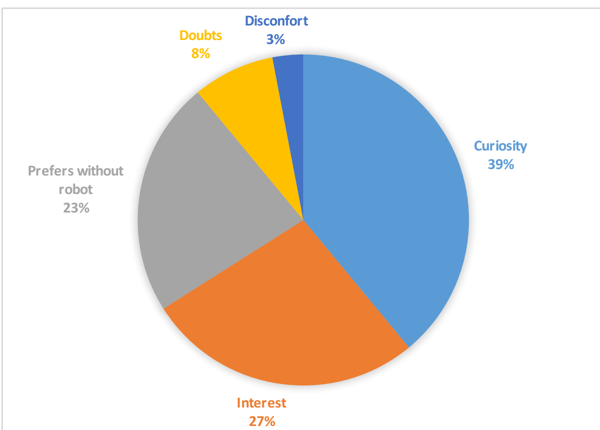

Figure 4: Opinion of patients on the integration of SAR in the CR program

3.2 Case Study

As described before, the sensor suite measures mainly six parameters (heart rate, cadence, step length, speed, inclination and the Borg scale) that are recorded in real-time. Fig 5 shows how these parameters change over the course of a normal session. As can be observed, the heart rate parameter is measured during the exercise as well as in the cool-down phase, hence, the recovery heart rate can be estimated. The BS is requested periodically during the session. However, the remaining parameters are measured only during the exercise stage, hence, an interruption in the data is observed. The speed is presented in miles per hour (Mph), since the treadmill and the protocol in the clinic uses this measurement unit.

According to the methodology previously defined, the patient attended to 16 sessions that were monitored by the SAR system. Fig 6 shows the average performance, namely the heart rate, speed and Borg scale for each session during the complete rehabilitation phase. Additionally, the tendencies of these parameters are shown (in red).

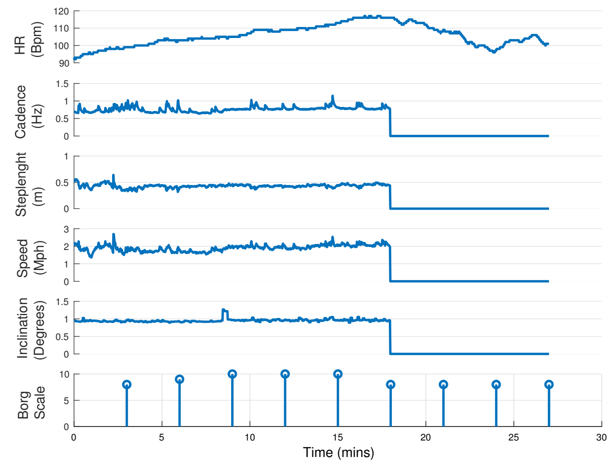

Figure 5: Physiological parameters of a patient during the session

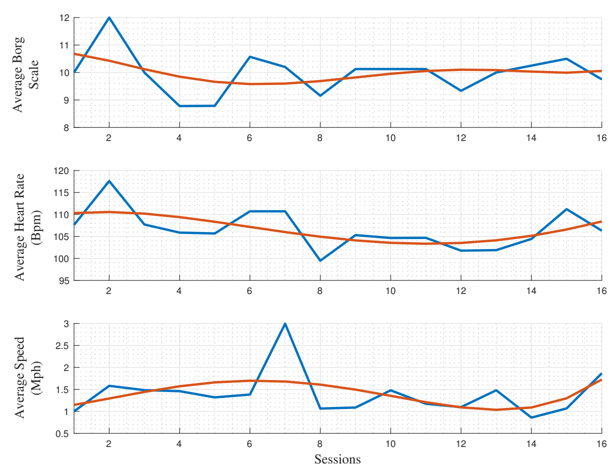

Figure 6: Physiological evolution of a patient during a standard phase II (in blue), and tendencies of parameters (in red)

The interaction, as defined in previous section, was measured by the response time and the amount of interventions of the robot in order to correct the posture of the patient. These metrics are displayed in Fig 7, where the average response time that the patient performed during each session is shown, as well as the number of interventions made by the robot for posture correction.

4 DISCUSSION

According to questions stated in the survey, there are two important results concerning the current application. (1) Most of the patients (37%) feel that they have had progress in their physical capacity and that they are able to see other positive results in their health

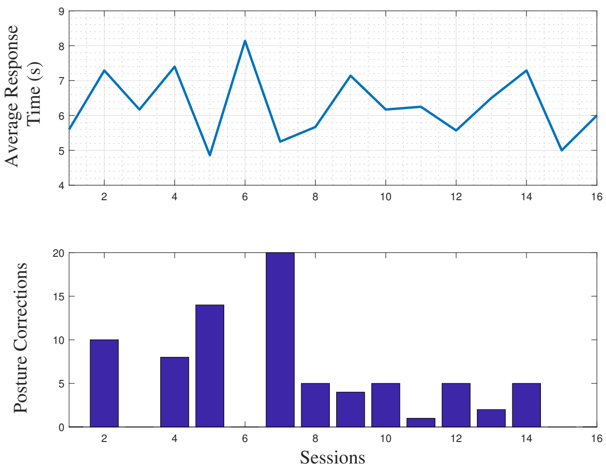

Figure 7: Interaction during cardiac rehabilitation phase II

conditions in the CR program. Also, 28% of the patients was satisfied with all the aspects of the CR program. The relatively low (8%) response rate on the "technology" aspect might be interpreted in two ways: first, the patients are attracted by the technology that currently operates in the institution and second, the other patients who did not select this option might be feeling the need for more technology in the sessions. (2) Regarding the integration of a social robot in the CR program, the majority of patients (66%) approach it positively, i.e. either with curiosity or interest. Nevertheless, 8% patients have doubts such as how the robot will be integrated in the sessions or if the robot will replace the medical staff, which they expressed further on. Finally, 26% of patients had a negative opinion, such that they preferred the therapy without a robot or would feel discomfort towards the integration of the social robot. However, the responses to the open question on explaining the negative response, suggested that they rejected the idea because they think that the robot is going to replace the doctors, so it was necessary to present the project and explain in detail how the integration would be made to show that the purpose of the robot was to aid the medical staff instead of replacing them.

The proposed SAR system shows that it is capable to store, process and represent all information related to the patient during each session, providing a useful tool for the analysis of the performance as well as the personalization of the therapies for each patient. In relation to the physiological data measured during the complete phase of the CR program, it is important to note that the information provided allows the analysis of the patient's progress along the sessions, which also provides monitoring whether the patient has achieved any physical or health improvement during the process. For this particular case, a slight reduction (from 110 to 106 Bpm) of the heart rate and the perceived level of intensity can be observed during the course of the therapy, which would suggest that the physical condition of this patient has improved along the sessions.

Additionally, the SAR system has provided valuable information that serves to assess the interaction between the patient and the robot (Fig 7). As can be observed, the first graph shows how fast the patient has attended to the requests (here, the Borg scale) that the robot made during the session. It would be expected that along the sessions, the patient would adapt to the system and interact with it in a more efficient way. For this reason, a decreasing rate for the response time would be desirable, since it would indicate that patients have adapted correctly to the system. In the case study presented, the response time does not decrease constantly over the course of the study, hence, there is no concrete evidence that the patient has adapted better to the system during the therapy. Nevertheless, the posture correction rate has shown a major decrease in the last sessions. This result would indicate that as a result of the corrections of the robot, the patient has adopted a better posture along the sessions and has required less corrections by the robot.

5 CONCLUSION

The results of the questionnaire show that cardiac rehabilitation is a potential field of action for SAR technologies. The patients have shown interest and curiosity towards the integration of social robots in the rehabilitation program.

This work presented the introduction of a SAR system to cardiac rehabilitation therapies. In order to evaluate the performance of the patient and its adaptability to the system, a case study of a patient with PCI is analyzed during a conventional phase II of the cardiac rehabilitation program. The results suggest a slight improvement for the patient by the end of the 16 sessions in terms of physiological parameters obtained during the session. Furthermore, it was possible to assess the interaction between the patient and the robot, which improved the posture of the patient as a result of the continuous monitoring during the session. This work was presented as a preliminary study carried out with one patient. Nevertheless, a larger study with 40 patients complete phase II of the CR program is currently being developed.

ACKNOWLEDGMENT

This work was supported in part by the Royal Academy of Engineering Industry Academia Partnership Programme project Human-Robot Interaction Strategies for Rehabilitation based on Socially Assistive Robotics (grant IAPP/1516/137, 2016-2018), and the EU H2020 Marie Sklodowska-Curie Actions ITN project APRIL (grant 674868), and the EU FP7 project DREAM (grant 611391).

REFERENCES

[1] Wilma A. Bainbridge, Justin W. Hart, Elizabeth S. Kim, and Brian Scassellati. 2011. The benefits of interactions with physically present robots over video-displayed agents. *International Journal of Social Robotics* 3, 1 (2011), 41–52. https://doi.org/10.1007/s12369-010-0082-7

[2] Joost Broekens, Marcel Heerink, and Henk Rosendal. 2009. Assistive social robots in elderly care: a review. *Gerontechnology* 8, 2 (2009), 94–103. https://doi.org/10.4017/gt.2009.08.02.002.00.

[3] A. Cherubini, D.T. Lowenthal, L.S. Williams, D. Maggio, P. Mecocci, and U. Senin. 1998. Physical activity and cardiovascular health in the elderly. *Aging Clinical and Experimental Research* 10, 1 (1998), 13–25.

[4] Ian K. Crombie, Linda Irvine, Brian Williams, Alison R. McGinnis, Peter W. Slane, Elizabeth M. Alder, and Marion E T McMurdo. 2004. Why older people do not participate in leisure time physical activity: A survey of activity levels, beliefs and deterrents. *Age and Ageing* 33, 3 (2004), 287–292. https://doi.org/10.1093/ageing/afh089

[5] David Feil-Seifer and Maja J Matarić. 2005. Defining socially assistive robotics. In *Rehabilitation Robotics, 2005. ICORR 2005. 9th International Conference on.* IEEE, 465–468.

[6] R. Gehle, K. Pitsch, T. Dankert, and S. Wrede. 2017. How to Open an Interaction Between Robot and Museum Visitor? Strategies to Establish a Focused Encounter in HRI. *Conference on Human-Robot Interaction (HRI '17)* (2017), 187–195. https://doi.org/10.1145/2909824.3020219

[7] Shang Guo, Jonathan Lenchner, Jonathan Connell, Mishal Dholakia, and Hidemasa Muta. 2017. Conversational Bootstrapping and Other Tricks of a Concierge Robot. *Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction - HRI '17* (2017), 73–81. https://doi.org/10.1145/2909824.3020232

[8] Jeonghye Han, Miheon Jo, Vicki Jones, and Jun H Jo. 2008. Comparative Study on the Educational Use of Home Robots for Children. *Journal of Information Processing Systems* 4, 4 (2008), 159–168. https://doi.org/10.3745/JIPS.2008.4.4.159

[9] Vicki Jones, Jun H. Jo, and Jeonghye Han. 2006. The Future of Robot-Assisted Learning in the Home. *International Journal of Pedagogies and Learning* 2, 1 (2006), 63–75. https://doi.org/10.5172/ijpl.2.1.63

[10] James Kennedy, Paul Baxter, and Tony Belpaeme. 2015. Comparing Robot Embodiments in a Guided Discovery Learning Interaction with Children. *International Journal of Social Robotics* 7, 2 (2015), 293–308. https://doi.org/10.1007/s12369-014-0277-4

[11] Cory D. Kidd and Cynthia Breazeal. 2008. Robots at home: Understanding long-term human-robot interaction. *2008 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS* (2008), 3230–3235. https://doi.org/10.1109/IROS.2008.4651113

[12] William Kraus and Steven Keteyian. 2007. *Cardiac Rehabilitation*. Humana Press, Totowa, N. J.

[13] Juan S. Lara, Jonathan Casas, Andres Aguirre, Marcela Munera, Monica Rincon-Roncancio, Bahar Irfan, Emmanuel Senft, Tony Belpaeme, and Carlos A. Cifuentes. 2017. Human-robot sensor interface for cardiac rehabilitation. In *2017 International Conference on Rehabilitation Robotics (ICORR)*. 1013–1018.

[14] Francisco Martín, Carlos E. Agüero, José M. Cañas, Meritxell Valenti, and Pablo Martínez-Martín. 2013. *International Journal of Advanced Robotic Systems* 10 (2013). https://doi.org/10.5772/54765

[15] Sao Mai Nguyen, Philippe Tanguy, and Olivier Remy-Neris. 2016. Computational architecture of a robot coach for physical exercises in kinaesthetic rehabilitation. *25th IEEE International Symposium on Robot and Human Interactive Communication, RO-MAN 2016* (2016), 1138–1143. https://doi.org/10.1109/ROMAN.2016.7745251

[16] Massimo F. Piepoli, Ugo Corrà, Paul Dendale, Ines Frederix, Eva Prescott, Jean Paul Schmid, Margaret Cupples, Christi Deaton, Patrick Doherty, Pantaleo Giannuzzi, Ian Graham, Tina Birgitte Hansen, Catriona Jennings, Ulf Landmesser, Pedro Marques-Vidal, Christiaan Vrints, David Walker, Hector Bueno, Donna Fitzsimons, and Antonio Pelliccia. 2017. Challenges in secondary prevention after acute myocardial infarction: A call for action. *European Journal of Cardiovascular Nursing* 16, 5 (2017), 369–380. https://doi.org/10.1177/1474515117702594

[17] Zhuoyu Shen and Yan Wu. 2016. Investigation of Practical Use of Humanoid Robots in Elderly Care Centres. *Proceedings of the Fourth International Conference on Human Agent Interaction - HAI '16* (2016), 63–66. https://doi.org/10.1145/2974804.2980485

[18] Gabriele Trovato, Josue G. Ramos, Helio Azevedo, Artemis Moroni, Silvia Magossi, Reid Simmons, Hiroyuki Ishii, and Atsuo Takanishi. 2017. A receptionist robot for Brazilian people: Study on interaction involving illiterates. *Paladyn* 8, 1 (2017), 1–17. https://doi.org/10.1515/pjbr-2017-0001